Dosimetric influence of pitch in patient positioning for radiotherapy of long treatment volumes; the usefulness of six degree of freedom couch

Stieb, Sonja ; Malla, Michelle ; Graydon, Shaun ; Riesterer, Oliver ; Klöck, Stephan ; Studer, Gabriela ; Tanadini-Lang, Stephanie

Abstract: OBJECTIVE: Pitch, the rotation around the transversal axis of the patient during radiotherapy has little impact on the dose distribution of small spherical treatment volumes; however it might affect treatment of long volumes requiring a correction with a six degree of freedom couch. METHODS: We included 10 patients each with nasopharyngeal carcinoma (NPC) and esophageal cancer, treated with volumetric modulated arc therapy. Pitch was simulated by tilting the planning CT in ventral and dorsal direction by ± 1.5° and ± 3°. Verification plans were calculated on the tilted datasets and were compared to the original plan and the dose constraints of the organs at risk (OAR). RESULTS: The deviation in dose to the planning target volume is increasing with the degree of pitch with mean changes of up to 2% for NPC and 1% for esophageal cancer. The most affected OAR in NPC patients are brainstem (max. dose +6.0%) and spinal cord (max. dose +10.0%) when tilted by 3° dorsally and lenses (max. dose +3.3%), oral mucosa (mean dose +2.6%) and parotid glands (mean dose +4.3%) when tilted by 3° ventrally. For esophageal cancer patients, there was no significant change in dose to any OAR. Whereas for esophageal cancer, all tilted treatment plans were still clinically acceptable regarding OAR, 5 NPC plans would no longer be acceptable with a pitch of 1.5° ventral (N = 1), 3° ventral (N = 2) and 3° dorsal (N = 2). CONCLUSION: Planning target volume coverage in both tumor entities was only slightly affected, but pitch errors could be relevant for OAR in NPC patients. ADVANCES IN KNOWLEDGE: A correction with a six degree of freedom couch is recommended for NPC patients with a pitch mismatch of more than 1.5° to avoid exceeded doses to the OAR.

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FULL PAPER

Dosimetric influence of pitch in patient positioning for radiotherapy of long treatment volumes; the usefulness of six degree of freedom couch

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Objective: Pitch, the rotation around the transversal axis of the patient during radiotherapy has little impact on the dose distribution of small spherical treatment volumes; however it might affect treatment of long volumes requiring a correction with a six degree of freedom couch.
Methods: We included 10 patients each with nasopharyngeal carcinoma (NPC) and esophageal cancer, treated with volumetric modulated arc therapy. Pitch was simulated by tilting the planning CT in ventral and dorsal direction by ± 1.5° and ± 3°. Verification plans were calculated on the tilted datasets and were compared to the original plan and the dose constraints of the organs at risk (OAR).
Results: The deviation in dose to the planning target volume is increasing with the degree of pitch with mean changes of up to 2% for NPC and 1% for esophageal cancer. The most affected OAR in NPC patients are brainstem (max. dose +6.0%) and spinal cord (max. dose +10.0%) when tilted by 3° dorsally and lenses (max. dose +3.3%), oral mucosa (mean dose +2.6%) and parotid glands (mean dose +4.3%) when tilted by 3° ventrally. For esophageal cancer patients, there was no significant change in dose to any OAR. Whereas for esophageal cancer, all tilted treatment plans were still clinically acceptable regarding OAR, 5 NPC plans would no longer be acceptable with a pitch of 1.5° ventral (*N* = 1), 3° ventral (*N* = 2) and 3° dorsal (*N* = 2).
Conclusion: Planning target volume coverage in both tumor entities was only slightly affected, but pitch errors could be relevant for OAR in NPC patients.
Advances in knowledge: A correction with a six degree of freedom couch is recommended for NPC patients with a pitch mismatch of more than 1.5° to avoid exceeded doses to the OAR.

INTRODUCTION

For patients with advanced stage, non-metastasized nasopharyngeal carcinoma (NPC) and esophageal cancer concurrent chemoradiation ais an integral part of curative intended therapy. Especially for those long treatment volumes, exact patient positioning is of high impact to ensure that the whole treatment volume is covered with the prescribed dose.

A conventional linear accelerator treatment couch allows manipulation of the patient in four degrees of freedom (DoF) [three translational degrees (*xyz*) and rotational degree yaw (rotation around sagittal axis)]. However, the rotational degrees pitch (rotation around the transversal axis) and roll (rotation around the longitudinal axis) are often not addressed.

Several publications have shown that rotational errors have a small impact on the dose distribution in the case of irradiation of small spherical volumes, such as brain metastases or prostates.[1–6] Peng et al showed that a rotational error of 3° reduces coverage of the clinical target volume in brain tumors treated with intensity modulated radiotherapy from 99.3 to 97.0%.[1] Similarly, Guckenberger et al concluded that rotational errors do not affect target coverage and conformity in brain metastases using volumetric arc therapy (VMAT) or static beams.[4] However, for geometrical reasons the impact of pitch might be more relevant in the case of long treatment volumes, because dose coverage might be compromised at the edges of the cranial or caudal end of the target volume and high doses might be shifted into organs at risk

(OAR). This becomes even more important considering the fact that nowadays, more and more intensity modulated radiation techniques are used, which produce highly conformal and complex dose distributions. There exists only limited data on the impact of a pitch on long treatment volumes.

Radiotherapy of head and neck and esophageal cancers are examples of extended treatment volumes. Patients with head and neck cancer may have rotational variations of up to 14° during the course of radiotherapy.[7] Mean deviations in pitch, roll and yaw of head and neck cancer patients amount to 0.5° ± 2.3°, 1.4° ± 3.2° and 0.5° ± 1.6°, respectively.[8] Similar deviations are reported by other authors.[7,9–12] Chen et al evaluated rotational set-up errors of esophageal cancer patients and found errors of up to 6.2° with mean differences of 1.0° ± 0.5°, 1.2° ± 1.2° and 1.1° ± 0.8° for pitch, roll and yaw, respectively.[13] According to mathematical calculations, a rotational error of 1.5° leads to misalignment at the edges of a 20 cm long planning target volume (PTV) of 2.6 mm and an error of 3° to a misalignment of 5.2 mm. Nowadays several robotic add-on systems for corrections in 6DoF are available to compensate for these rotational variations (*e.g.* PerfectPitch™ 6DoF couch (Varian Medical Systems, Palo Alto, CA), HexaPOD™ evo RT system (Elekta AB, Stockholm, Sweden), Protura™ Robotic Patient Positioning System (CIVCO Medical Solutions, Coralville, IA etc.). In this study, we investigated the dosimetric influence of pitch for long treatment volumes such as nasopharyngeal carcinoma and esophageal cancer treated with VMAT. Dosimetric differences in the PTV and relevant OAR due to a pitch of 1.5° and 3° were evaluated and the degree of mismatch at which the patient should be repositioned or corrected with the use of a 6DoF couch to avoid exceeded doses to the OAR was assessed.

METHODS AND MATERIALS/PATIENTS

Patient selection

Altogether, 20 patients have been retrospectively included in this study: 10 patients with NPC and 10 patients with esophageal cancer. All patients were treated with VMAT at the University Hospital Zurich between 2010 and 2013. Patients with NPC have been randomly chosen from an internal database. In the case of esophageal cancer, patients with a long PTV in the craniocaudal direction were selected (for patient details Table 1). Specific exclusion criteria were not applied. Patients with NPC were treated with 66–70 Gy in 33–35 fractions and esophageal cancer patients with 41.4–54 Gy in 23–28 fractions. Treatment volumes were created as follows: In the case of NPC the gross tumor volume was expanded by 1 cm and adapted anatomically (max. 3 mm beyond anatomical boundaries) to create the 66–70 Gy PTV (PTV1). 69.6–70 Gy was the standard dose administered, whereas 66 Gy was given in case of large high-dose treatment volumes. The entire nasopharynx as area of high risk for microscopic disease received at least 60 Gy (intermediary dose volume, PTV2) and the elective cervical lymph nodes, usually level II–V bilaterally, 54 Gy (PTV3). In the case of esophageal cancer the gross tumor volume was expanded by 1.5 cm axially, adapted to vertebral bodies, and 4 cm craniocaudally, added by the locoregional lymph nodes [paraesophageal, celiac (cancer of lower esophagus), supraclavicular (cancer of upper esophagus)] to create the PTV. The maximal length of PTV in NPC ranged from 4.7 to 13.7 cm for PTV1 and 11.7–23.0 cm for the sum of the PTVs; in esophageal cancer, the PTV ranged from 20.4 to 31.6 cm.

Table 1. Patient and treatment parameters

	NPC	Esophageal cancer
	N	N
Stage		
II	3 (30%)	2 (20%)
III	4 (40%)	6 (60%)
IV	3 (30%)	2 (20%)
Dose prescription NPC		
70 Gy/35 fx	6 (60%)	
69.6 Gy/33 fx	2 (20%)	
68 Gy/34 fx	1 (10%)	
66 Gy/33 fx	1 (10%)	
Dose prescription esophageal cancer		
54 Gy/27 fx		1 (10%)
50.4 Gy/28 fx		1 (10%)
50 Gy/25 fx		2 (20%)
45 Gy/25 fx		1 (10%)
41.4 Gy/23 fx		4 (40%)
Size high dose PTV		
Mean [cm^3]/Median [cm^3]	197.1/191.5	1159.6/1072.7
SD [cm^3]	68.9	321.6
Range [cm^3]	98.4–339.1	862.0–1764.4
Max. length PTV		
Mean [cm] / Median [cm]	20.0/20.6	25.5/24.6
SD [cm]	3.2	3.7
Range [cm]	11.7–23.0	20.4–31.6
Arcs		
2	8 (80%)	8 (80%)
3	1 (10%)	2 (20%)
4	1 (10%)	

fx, fractions; N, number of patients if not indicated otherwise; NPC, nasopharyngeal carcinoma; PTV, planning target volume; SD, standard deviation

Treatment planning

VMAT treatment planning was performed in Eclipse treatment planning system (TPS) (v. 11, Varian Medical Systems, Palo Alto, CA) using progressive resolution optimizer (PRO 11.0.31). Dose was calculated using the analytic anisotropic algorithm (AAA 11.0.31). Depending on the complexity of the PTV, 2–4 coplanar arcs were used. For esophageal cancer, avoidance sectors were used to spare the lungs.

Table 2. Institutional dose constraints of organs at risk for NPC and esophageal cancer patients

	Maximum dose	Mean dose
NPC		
Brainstem	60 Gy	
Optic nerves/Chiasm	54 Gy	
Lens		5 Gy
Spinal cord	50 Gy	
Brain	As low as possible	
Eyes	54 Gy	
Lacrimal gland	45 Gy	
Parotid gland		26 Gy
Oral mucosa	As low as possible	
Cochlea		45 Gy
Esophageal cancer		
Spinal cord	45 Gy	
Lungs		20 Gy
Heart	As low as possible	

NPC, nasopharyngeal carcinoma.

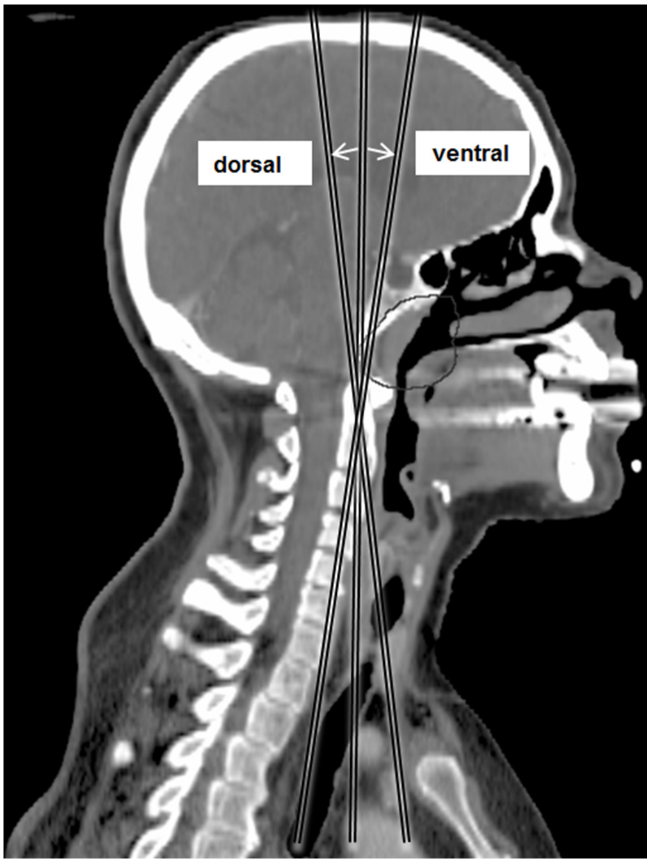
All patients were treated on a Trilogy or TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA). Patients with NPC were fixated with a 5-point head and neck immobilization mask (Civco Medical Solutions, Armonk, NY). Patients with esophageal cancer were positioned supine on the treatment table using a wing board for arm positioning. Image guidance was performed for all patients using daily orthogonal kilovoltage (kV) image pairs and at least once per week kV cone beam CT(CBCT). For both treatment sites, the aim was to cover 95% of the PTV with at least 95% of the prescribed dose (V95%). However, in cases where air cavities or lung tissue were included in the PTV, the PTV was close to the surface or in order to reduce the dose to the OAR, reduced PTV coverage was accepted.

The mandatory dose constraints for OAR in patients with NPC were a maximum dose to the spinal cord of 50 Gy, a maximum dose to the optical nerves and chiasm of 54 Gy, a maximum dose to the brainstem of 60 Gy and a mean dose to the parotid glands of 26 Gy and to the lenses of 5 Gy. For esophageal cancer, the dose constraints for OAR were a maximum dose to the spinal cord of 45 Gy and a mean dose to the lungs of 20 Gy. For both sites other OAR (brain, eyes, lacrimal glands, oral mucosa, cochlea, heart) have been optimized in respect to the accumulated dose, to meet the institutional dose standards as good as possible (Table 2).

Reference plans

Pitch was simulated by tilting the planning CT around the transversal axis in ventral and dorsal direction by ± 1.5° and ± 3° (Figure 1). The value of 3° was chosen, because it is the largest adjustment that can be performed with most commercially available 6DoF couches. In addition, 1.5° was chosen based on our clinical experience that this degree of pitch frequently occurs. First, a copy of the original CT data set was made in the TPS,

Figure 1. Schema of pitch in ventral and dorsal direction in a patient with NPC. The grey line represents the high dose PTV. High dose PTV as contour in grey. NPC, nasopharyngeal carcinoma; PTV, planning target volume.



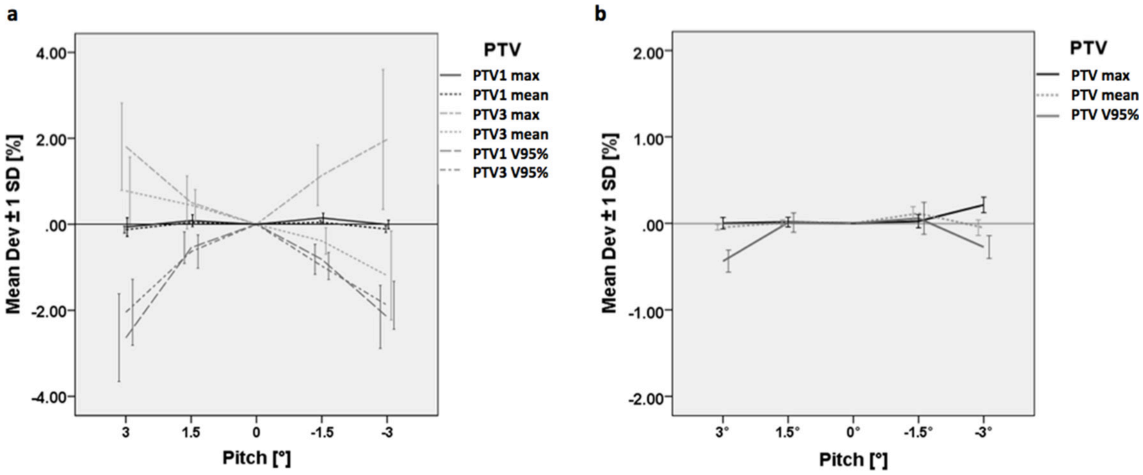
identifying DICOM tags were deleted with Matlab v. 8.2 (Mathworks, Natick, MA) and PTV structures and structures of OAR were copied onto the CT data set, again in the TPS. Then, the data set was tilted with all the structures in the TPS around the middle of the dens axis for nasopharyngeal volumes and around the geometric middle of the PTV for esophageal volumes. Then, respective plans with the same pre-set values were calculated on the four tilted data sets for each patient.

PTV coverage and mean and maximum dose to the OAR were compared to the original plan and to the dose constraints of the OAR. In the case of NPC, the following OAR were evaluated: brain, brainstem, chiasm, optical nerves, spinal cord, lenses, oral mucosa and parotid glands. For esophageal cancer, spinal cord, lungs, heart, liver, intestines and kidneys were analyzed as OAR.

Statistical analysis

Statistical analysis was done using the software program SPSS v. 22 (IBM SPSS Statistic Software, Armonk, NY). Differences in mean and maximum dose to PTVs and OAR were calculated and mean, median and range of these differences were determined. Box-Whisker-Plots for OAR and line charts for PTVs were created to show dosimetric changes in these structures in the tilted treatment plans. The two-sided Wilcoxon signed-rank test was used to test whether the differences between the maximum

Figure 2. Mean deviation in maximum and mean dose of the PTV and PTV coverage for pitch of ±1.5° and ±3° in NPC (a) and esophageal cancer patients (b). Error bars are showing one standard deviation. Positive value = ventral pitch, negative value = dorsal pitch. Dev, deviation; NPC, nasopharyngeal carcinoma; PTV, planning target volume; SD, standard deviation; V95%, dose which covers 95% of the PTV.



and mean dose of the PTVs and OAR and the PTV coverage of the tilted plans compared to the original plan were statistically significant to a p-value of ≤0.05.

RESULTS

Planning target volume

Figure 2a shows the changes in mean and maximum dose to the PTV of the 10 NPC patients tilted ventrally and dorsally by 1.5° and 3°. Deviation in dose to the PTV is increasing with the degree of pitch, but the effect appears to be relatively small (mean deviation below 3%). Whereas the mean and maximum dose to the PTV1 is nearly constant, the mean V95% of PTV1 varied by a mean value of up to 2.6% with a pitch of 3° ventrally. The average mean and maximum dose to the PTV3 and average V95% of PTV3 changed at maximum by 2.0%. For one patient, a deviation of 9.2% for the maximum value of PTV3 was recorded when tilted by 3° dorsally. In this patient, there was a hotspot at the border of PTV1, which was shifted into PTV3.

For esophageal cancer patients, a pitch of 1.5° and 3° resulted in even less variation in dose to the PTV and PTV coverage with mean changes of up to 0.9% when tilted ventrally (Figure 2b). Statistically significant changes could only be detected for maximum dose to the PTV when tilted by 3° dorsally (p = 0.038) and for PTV V95% when tilted by 3° ventrally (p = 0.013).

Organs at risk

The OAR most affected by a change of the pitch angle in NPC patients were brainstem, spinal cord, lenses, oral mucosa and parotid glands (Table 3, Figure 3), with dose variations of up to 35% in the optical nerves of one patient. Statistically significant mean dose deviations ranged up to 10.0% for the maximal dose to the spinal cord. An example of a patient that had a huge change in the dose to the brainstem due to the location close to the high dose PTV1 is shown in Figure 4. The mean dose to the brain and the mean and maximum dose to the chiasm and optical nerves did not change significantly when the head was tilted ventrally or dorsally by 1.5° and 3°. The initial non-tilted plan met in 6/10 cases our institutional OAR tolerances. Two plans exceeded the tolerance dose of the brainstem (max. dose of 62.5 and 63.0 Gy, respectively) because the PTV was located less than 5 mm away from it. In another initial plan. the dose to the ipsilateral optical nerve (max. dose of 61.8 Gy) was exceeded since it was located adjacent to the PTV. In the last case, the PTV including positive lymph nodes at both sides of the neck was located over the whole length of the parotid glands and therefore exceeded their tolerance dose (mean dose left 28.8 Gy and right 27.3 Gy, respectively). With a pitch of ± 1.5° and ± 3°, all patients who initially exceeded the tolerance dose of at least one OAR also exceeded the tolerance dose in the tilted plans. Two more patients, whose plans were initially below the dose constraints, exceeded the OAR tolerance dose at 1.5° ventral (N = 1), 3° ventral (N = 2) and 3° dorsal (N = 2). Altogether, 21/40 tilted NPC treatment plans would no longer be acceptable according to at least one of the dose constraints of the OAR (number of plans exceeding the dose constraints according to pitch: 0°: N = 4; +1.5°: N = 5; −1.5°: N = 4; +3°: N = 6; −3°: N = 6).

For esophageal cancer patients, there was no significant change in dose to any OAR. The largest difference was found for the maximum dose to the bowel with a deviation of +1.0% when tilted by 3° ventrally. None of the OAR exceeded the organ tolerance due to the pitch of the patient.

DISCUSSION

The dosimetric influence of a tilt in the patient position during the treatment compared to the initial treatment plan was evaluated for patients with NPC and esophageal cancer. The influence of a tilt by 1.5° and 3° in ventral and dorsal direction was clinically relevant for nasopharyngeal volumes but not for esophageal volumes. For esophageal cancer patients, all treatment plans were clinically acceptable with a pitch of ± 1.5° and ± 3°. For patients with NPC, 4/10 plans initially exceeded the organ tolerance dose of at least one OAR compared to 21/40 tilted plans,

Table 3. Mean dose deviation in NPC patients dependent on degree and direction of pitch

	Dose deviation NPC [%]							
	3° ventral		1.5° ventral		1.5° dorsal		3° dorsal	
PTV								
PTV1 max	−0.1 (0.6)	n.s.	4.5 (7.3)	n.s.	−3.8 (4.9)	n.s.	−4.6 (7.8)	n.s.
PTV1 mean	−0.1 (0.2)	n.s.	1.9 (5.4)	n.s.	−1.4 (3.8)	n.s.	−1.0 (6.1)	n.s.
PTV3 max	1.8 (3.0)	n.s.	−0.3 (1.9);	n.s.	0.5 (1.3)	n.s.	1.7 (4.1)	n.s.
PTV3 mean	0.8 (2.3)	n.s.	0.45 (1.1)	$p = 0.022$	−0.4 (0.9)	$p = 0.022$	−1.2 (3.1)	$p = 0.013$
PTV1 V95%	−2.6 (3.0)	$p = 0.013$	−0.5 (1.1)	n.s.	−0.8 (1.0)	n.s.	−2.2 (2.2)	$p = 0.017$
PTV3 V95%	−2.0 (2.3)	$p = 0.022$	−0.6 (1.2)	n.s.	−1.0 (0.9)	$p = 0.013$	−1.9 (1.7)	$p = 0.009$
OAR								
Chiasm max	5.8 (9.7)	n.s.	4.5 (7.3)	n.s.	−3.8 (4.9)	n.s.	−4.6 (7.8)	n.s.
Chiasm mean	3.0 (7.7)	n.s.	1.9 (5.4)	n.s.	−1.4 (3.8)	n.s.	−1.0 (6.1)	n.s.
Brain mean	−1.3 (2.7)	n.s.	−0.3 (1.9)	n.s.	0.5 (1.3)	n.s.	1.7 (4.1)	n.s.
Brainstem max	−3.7 (3.3)	$p = 0.013$	−1.7 (1.9)	$p = 0.037$	2.9 (3.1)	$p = 0.022$	6.0 (6.3)	$p = 0.017$
Brainstem mean	−2.4 (4.0)	$p = 0.028$	−0.7 (2.5)	n.s.	1.3 (2.3)	$p = 0.047$	3.0 (5.5)	$p = 0.037$
Lens max (i)	3.3 (3.0)	$p = 0.022$	2.5 (2.5)	$p = 0.017$	−1.4 (2.1)	n.s.	−2.3 (2.9)	$p = 0.037$
Lens max (c)	3.1 (3.3)	$p = 0.037$	1.9 (2.7)	n.s.	−1.0 (1.6)	n.s.	−1.1 (3.3)	n.s.
Spinal cord max	−3.9 (5.2)	$p = 0.028$	−2.2 (3.0)	$p = 0.047$	5.1 (4.2)	$p = 0.017$	10.0 (9.9)	$p = 0.013$
Spinal cord mean	−0.5 (3.2)	n.s.	−0.6 (0.6)	$p = 0.013$	1.9 (3.5)	$p = 0.013$	3.1 (4.1)	$p = 0.013$
Oral mucosa mean	2.6 (2.5)	$p = 0.022$	1.0 (1.3)	n.s.	−1.6 (1.3)	$p = 0.013$	−2.8 (3.0)	$p = 0.017$
Parotid gland mean (i)	4.0 (4.1)	$p = 0.017$	2.0 (2.2)	$p = 0.022$	−1.2 (2.0)	$p = 0.047$	−3.1 (3.2)	$p = 0.014$
Parotid gland mean (c)	4.3 (4.0)	$p = 0.007$	1.8 (1.7)	$p = 0.013$	−2.0 (1.8)	$p = 0.009$	−3.1 (3.2)	$p = 0.013$
Optical nerve max (i)	1.0 (14.2)	n.s.	−0.6 (13.2)	n.s.	−3.0 (4.8)	n.s.	−3.4 (5.5)	n.s.
Optical nerve max (c)	1.6 (15.1)	n.s.	0.3 (14.2)	n.s.	−3.5 (3.8)	$p = 0.047$	−3.7 (7.7)	n.s.

c, contralateral; i, ipsilateral; NPC, nasopharyngeal carcinoma; n.s., not significant; PTV, planning target volume; V95%, dose which covers 95% of the PTV.
Patients were tilted ventrally and dorsally by 1.5° and 3°. Standard deviations are shown in bracket.

especially with a pitch of 3°. For nasopharyngeal volumes, it is therefore useful to correct a pitch with a 6DoF treatment couch or with repositioning of the patient. This is especially important for patients where a dose constraint is already exceeded or near the tolerance level in the initial treatment plan. The PTV coverage was only slightly affected by a pitch of up to 3° with a mean dose variation of at maximum 2.6% for both nasopharyngeal and esophageal cancer patients. As dose constrains for OAR are always prioritized over PTV coverage, there was no particular institutional dose constraint for that.

Several studies exist evaluating the influence of a patient's tilt on the dose distribution for intra- and extracranial stereotactic as well as for prostate volumes.[1,2,4,14] All of these studies showed minor deviation in dose to the OAR and PTV coverage for a rotational misalignment of up to 3°. However, very few studies exist evaluating the effect of a rotational misalignment for long treatment volumes.[3,15] Since a rotational error of 3° corresponds to a lateral offset of 0.5 mm 1 cm away from the center of the target and of 5.2 mm 10 cm away, the largest effect of a rotational misalignment is expected for long treatment volumes. Guckenberger et al evaluated the influence of rotational setup errors for different treatment sites. They found that rotational errors were only of clinical relevance in patients with elongated, non-spherical target volumes and sharp dose gradients to adjacent OAR.[3] Similarly, Fu et al showed that the coverage of the clinical target volume in head and neck cancer patients can decrease as much as 9.8% for individual fractions, assuming realistic set-up errors of up to 5°.[15] We compared two different treatment sites with large target volumes. Interestingly, we could show that for esophageal cancer the effect on the target coverage and the change in dose to the OAR of a rotational error is much smaller compared to NPC. The PTV coverage is less affected in esophageal tumor volumes, because the main dose contribution comes from anterior and posterior direction in order to spare the lung tissue. Whereas a tilt in ventral or dorsal direction could have a large influence on the target coverage for lateral fields, there is only a minor influence for anterior and posterior fields. In contrast, for head and neck volumes a large dose contribution comes from lateral fields. Mainly, for the same reason the change in dose to the OAR is smaller for esophageal treatment volumes compared to head and neck treatment volumes. In

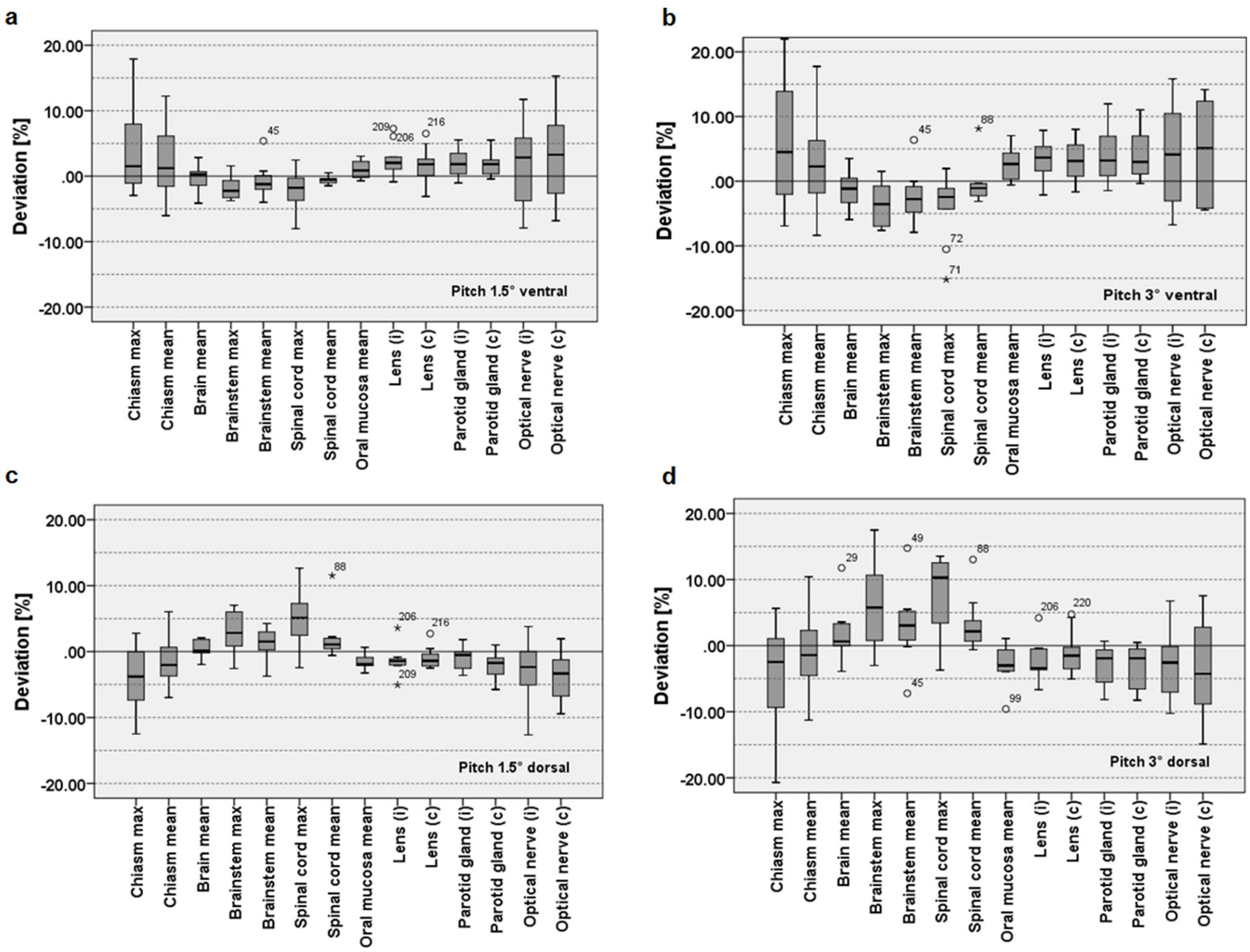


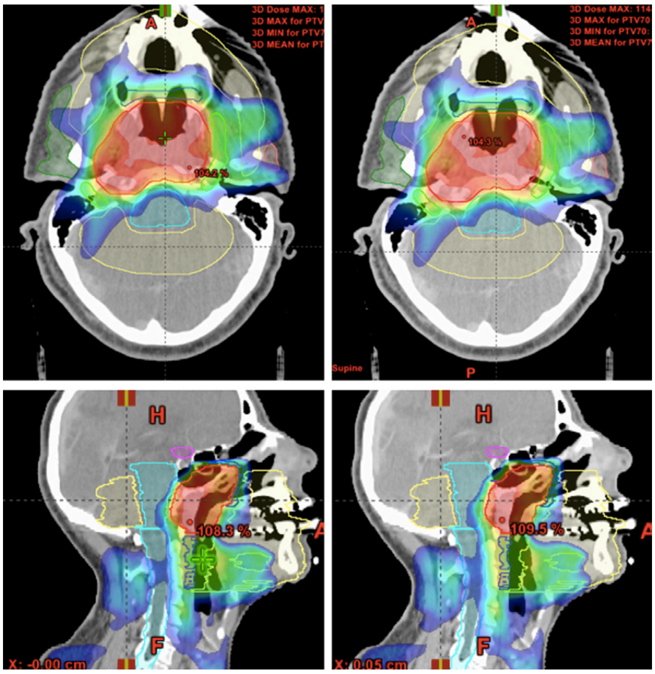
Figure 3. Box-Whisker-Plots showing percentage changes in dose to OAR in NPC patients if the patient is tilted ventrally (a–b) and dorsally (c–d) by 1.5° and 3°. c, contralateral; i, ipsilateral; NPC, nasopharyngeal carcinoma; OAR, organs at risk.

addition, in the case of head and neck treatment volumes OAR are usually closer to the PTV and therefore are more prone to setup errors due to rotations. This is the first study showing that the treatment technique significantly influences the robustness against rotational set-up errors and that therefore, the benefit of compensation with a 6DoF couch has to be carefully evaluated per treatment site.

Since the dose to the OAR in NPC patients is usually already near the tolerance level, a minor difference in dose could lead to severe side effects. Radiation-induced toxicity is already high in NPC patients with acute toxic reactions of the oral mucosa, salivary glands and skin. Incidence rates for acute radiation induced grade 3 toxicities are reported for mucositis (35%), dysphagia (11%), xerostomia (6%) and skin reactions (4%). Late radiation induced toxicity is less common with 3% grade 3 xerostomia.[16] In esophageal cancer, dose to the PTV is much less compared to the dose for NPC patients with up to 54 Gy, so no extensive toxicity is expected for lung and spinal cord when there is a minor dose variation.

In this study we analyzed the impact of pitch but not of roll or yaw. In addition, translational set-up errors were not evaluated because they can be compensated with help of on-board imaging and currently available 4DoF tables integrated in modern linear accelerators. The effect of roll of the patient was expected to be less compared to pitch due to the smaller extension of the PTVs in that direction. Kim et al evaluated the dosimetric changes due to a roll of 3° in intensity modulated radiotherapy plans of head and neck cancer patients and found an average increase in the maximum dose to the spinal cord of 3.1% but no effect on the dose to the parotid glands.[17] Our study on the effect of a 3° pitch on the dosimetry of NPC VMAT plans showed a larger average change in the maximum dose to the spinal cord of −3.9% (3° ventral) / 10.0% (3° dorsal) and an average change of the mean dose of −0.5% (3° ventral) / 3.1% (3° dorsal). Several studies have shown pitch and roll values for head and neck cancer patients of up to 14°.[7–10] In this study, we have evaluated the effect of a pitch of ± 1.5° and ± 3°. The effect of a 14° pitch is expected to be much higher. Nevertheless, we have decided to only evaluate the effect of up to 3°, because most of the available 6DoF treatment tables are not able to adjust more than 3°. According to our current clinical protocol, we would correct for a pitch or roll between 1° and 3° by means of the rotational degrees of freedom of the couch. Deviations of more than 3° would induce us to reposition the patient. Additionally, it was shown by several studies

Figure 4. Dose distribution of the original plan (left) and the plan on the 3° tilted CT data set in dorsal direction (right). The dose to the brainstem (light blue) increased with the pitch because the high dose area of the PTV1 (in red) shifted towards the brainstem.



that with a thermoplasik mask system, pitch and roll errors can be reduced to below 4°,[10,18] which might improve with an additional biteblock.[19] One limitation of the study is that we assumed that the patients are rigid bodies with no deformation during the course of radiotherapy. Especially, in the head and neck area where the spine is more flexible, the degree of pitch increases with the distance, which makes OARs near the center of the PTV less affected by pitch. Therefore, the calculated values like the mean dose to the oral mucosa may be too high in our analysis. Further studies, *e.g.* on CBCTs of these patients with adapted contours would be strongly desirable to solve this problem. Another limitation is that we included four esophageal cancer patients in our study population who were irradiated with only 41.4 Gy. With a higher dose of up to 60 Gy in the case of definitive treatment the dose to the lungs would probably be higher and therefore more likely exceed the tolerance level. Furthermore, only 10 patients each were included in the study as examples for nasopharyngeal and esophageal cancer patients respectively, possibly reducing the true effect of pitch calculated in this dosimetric study.

CONCLUSION

PTV coverage in NPC and esophageal cancer patients was only slightly affected, but pitch error could be relevant for OAR in NPC patients. Therefore, a correction is recommended for NPC patients, even with a pitch mismatch of 1.5° compared to the initial treatment plan. In the latter situation, the use of a 6DoF table might be clinically beneficial by executing these corrections without repositioning the patient.

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ETHICAL APPROVAL

This study was approved by the local ethics committee.

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